

photograph: David. O. Brown

Anthropogenic Noise and the Channel Islands National Marine Sanctuary

*How Noise Affects Sanctuary Resources,
and What We Can Do About It*

A report by the Environmental Defense Center, Santa Barbara, CA
www.EDCnet.org

Primary author: Shiva Polefka, Research Fellow
Project director: Linda Krop, Chief Counsel

September 28, 2004

Made possible by grants from Environmental Defense and the Marisla Foundation.

Table of Contents

| | |
|---|--------------------|
| Executive Summary..... | page 1 |
| Introduction..... | page 6 |
| Large Vessel Traffic..... | page 9 |
| Active Sonar..... | page 19 |
| High Energy Seismic Surveying..... | page 26 |
| Small Ships, Boats and Personal Watercraft..... | page 30 |
| Oil and Gas Development..... | page 34 |
| Acoustic Thermometry..... | page 35 |
| Recommendations and Ideas for Research..... | page 37 |
| Citations..... | page 42 |
| <i>Appendix A: Basics of Acoustics Science.....</i> | <i>page 48</i> |
| <i>Appendix B: Masking.....</i> | <i>page 50</i> |

EXECUTIVE SUMMARY

I. Background

In recent years, the emergence of human activities and technologies that emit extremely high levels of sound into the ocean have focused public, scientific and, to a lesser extent, regulatory attention on anthropogenic noise and its known and potential impacts on marine ecology. Concurrently, an array of data has arisen suggesting that the diverse array of anthropogenic noise sources in the ocean have a similarly broad spectrum of implications— from neutral to fatal— for marine wildlife. This increased scrutiny has also revealed a disturbing lack of understanding of marine bioacoustics and biological interaction with human-generated noise.

From this context, the Environmental Defense Center (EDC), a Santa Barbara-based non-profit environmental law firm, and the Conservation Working Group (CWG) of the Channel Islands National Marine Sanctuary Advisory Council, identified the need to investigate and better understand a) the acoustic environment of the Channel Islands National Marine Sanctuary (the Sanctuary, or CINMS), b) how the biological communities of the Sanctuary interact or depend on sound, and c) how the array of human activities off the South Coast of California alter or impact the Sanctuary's acoustic environment and sound-sensitive or sound-dependant wildlife. EDC, the CWG and other parties believe that the research necessary for answering these questions can also be applied to management of current activities that emit harmful noise into the Sanctuary, and to proactively inform and advise management of noisy human activities before emitted sound levels become deleterious to the Sanctuary's unique and precious biodiversity.

This document aims to initiate such a process through identification of all activities producing significant noise in CINMS, and through review and discussion of existing marine bioacoustics research and expertise that are pertinent to the wildlife in and around CINMS. Each sound-producing activity is identified and discussed individually in terms of physical characteristics, projected trends in noise output in CINMS (based on proliferation or decline of the activity), and the local biological communities affected by that activity's noise. Activities are arranged in order of their assessed threat to Sanctuary resources. This format organizes the vast field of anthropogenic noise and marine ecology into a set of locally pertinent topics more tractable to both resource managers and the public.

Finally, the report concludes with specific recommendations for research in the areas of science and policy. These recommendations are intended to assist CINMS in responding to threats and minimizing acoustic impacts to Sanctuary wildlife.

II. Findings

At present, researchers have documented that sound that is short in duration but sufficiently loud, such as underwater explosions, pinging from tactical naval sonar, and airgun blasts from seismic surveying, can cause harmful to fatal physical damage to organs and hearing tissues of certain marine life— particularly marine mammals and fishes— which suffer such exposure (Todd et al. 1996; Evans and England 2001; McCauley et al. 2003). Cumulative exposure to less intense sound over a longer duration, such as vessel traffic noise next to busy harbors, ports, or shipping lanes, can also cause temporary or permanent damage to hearing tissue in marine animals, as well as obscure, or *mask*, biologically vital or important sound from predators, prey, mates or other conspecifics (i.e. other members of an individual's species) (Richardson et al. 1995). All such impacts can be associated with costs in survival and reproduction; such impacts also imply costs for the ecosystems of which impacted species are a part (NRC 2003). The Sanctuary's biological resources are exposed to anthropogenic sound of both types, from a variety of human activities within or around CINMS that have occurred historically, that occur today, and that may resume or will likely continue in the future.

In the field of bioacoustics (the study of animal sounds and hearing), cetaceans (marine mammals such as whales and dolphins) and pinnipeds (seals and sea lions) are the most studied of marine wildlife (Popper 2003). While researchers have much more to learn about the importance of listening and sound production to these creatures in marine ecosystems, little doubt remains that anthropogenic noise can impact these species. Simmonds and Dolman (1999) summarize the documented spectrum of effects on individual cetaceans from anthropogenic noise:

- *Physical: non-auditory (damage to body tissue, induction of air bubble growth and tissue bends) and auditory (gross damage to ears, permanent hearing threshold shift, temporary hearing threshold shift);*
- *Perceptual: masking of communication with conspecifics, masking of other biologically important noises, interference with ability to acoustically interpret environment, adaptive shifting of vocalizations (with efficiency and energetic consequences);*
- *Behavioral: gross interruption of normal behavior (i.e. behavior acutely changed for a period of time), behavior modified (i.e. behavior continues but is less effective/efficient), displacement from area (short or long term);*
- *Chronic/Stress: decreased ability of individual, increased potential for impacts from negative cumulative effects (e.g. chemical pollutants combined with noise-induced stress), sensitization to noise (or other stresses) - exacerbating other effects, habituation to noise - causing animals to remain close to damaging noise sources;*
- *Indirect effects: reduced availability of prey. Consequently, physiological consequences are various: energetic implications, stress, hearing impairment (auditory damage and masking), non-auditory physical damages, strandings. In addition, noise can also alter feeding, foraging, resting, socializing and*

breeding behaviors, and the detrimental impact is likely to be particularly severe in cases where cetaceans are temporarily or permanently displaced from areas that are important for feeding or breeding.

Synergetic effects with other human activities and environmental alterations are worth re-emphasizing: examples include increased shipstrike of sperm whales due to threshold shift (hearing loss) from, or habituation to, large-vessel traffic noise exposure (André *et al.* 1998), and in killer whales, chronic stress from constant exposure to small vessel traffic noise reducing immune response to anthropogenic pollutants (e.g. PCBs), and pathogens (Erbe 2002). Because CINMS provides habitat for populations of many endangered cetacean species recovering from industrial whaling, and because human activities continue to impinge on population recovery in a variety of ways, anthropogenic noise must be considered for the impact it contributes both in isolation and in concert with other environmental factors.

While Simmonds and Dolman compiled this impact list specifically for cetaceans, our less developed understanding of noise impacts to fish suggests that many species may suffer individual and population impacts in similar ways. Recent studies reveal that some fish species have significant aural acuity, which they depend on for reproduction, foraging, predator avoidance, navigation and other biologically critical behavior. Evidence is also emerging that some fish produce sounds for communication with conspecifics, associated with reproduction and schooling behavior. All these biologically important phenomena may be impinged upon by excessive increases in background noise or through damage to the hearing tissue from excessive exposure. Furthermore, fish egg viability may be reduced by excessive exposure to sound waves, impacting a population's recruitment (Popper 2003).

Anatomical and ecological acoustical research on pinnipeds continues to progress, revealing more about the hearing specialties of known pinniped species, as well as the potential for anthropogenic noise to mask critical acoustic signals such as conspecific vocalizations and prey noises, which seals and sea lions are believed to rely heavily on in foraging (Southall *et al.* 2000).

At present, little is known about hearing or sound production in marine reptiles or invertebrates, or the impacts of anthropogenic noise on such species. However, exposure to impulsive sound at close range from airguns or underwater explosions is likely to be harmful or fatal merely from the energies involved in such discharges (NRC 2003).

Of the consequential activities in CINMS discussed below, large vessel traffic (defined as ships 85m and longer) represents the preeminent source of anthropogenic noise and the primary acoustic threat to Sanctuary resources. This primacy emerges from a combination of factors, including the levels of pervasive low-frequency sound emitted underwater by individual cargo ships and tankers (Ross 1976), and the volume of such vessel traffic through CINMS. Traffic volume is a factor of the geographic location of the Sanctuary vis-à-vis major commercial ports such as Los Angeles/Long Beach and San

Francisco, and the continuing growth of international trade, specifically between the US and Asia, which depends enormously on ship transport (Wignall and Womersley 2004, Westwood et al. 2002). Roughly 17 large commercial vessels pass through or near the Sanctuary daily. Based on current research, the sound emissions from this ship traffic comprise the greatest contribution of noise pollution into Sanctuary waters, emissions that may significantly impact the hearing anatomy, intraspecies communication, navigation, foraging and reproduction of resident cetaceans, fishes and pinnipeds.

Mid- and low frequency active sonars used by the US Navy, and scientific and commercial seismic surveying, also represent significant if relatively isolated and sporadic threats to Sanctuary ecology (Evans and England 2001, NRC 2003). Sound from these activities has been shown to cause trauma and death in fishes and marine mammals (life-threatening trauma to marine mammals from seismic surveying has yet to be conclusively demonstrated, though circumstantial evidence exists) (CBD v. NSF 2002). While some guidelines exist that protect areas of rich biological diversity such as marine sanctuaries from these activities (e.g. Evans and England 2001, HESS 1999), trends in the proliferation of military technology, deep-water oil exploration and production, and geological research suggest that CINMS may be faced with noise from these activities in the future.

The limited data available for review suggest that small ship and boat traffic (roughly, vessels under 85 meters in length) is not currently a significant acoustic threat to CINMS wildlife, due to a diffuse temporal and spatial distribution of these smaller engine-powered vessels within the Sanctuary. Nonetheless, deliberate, illegal chasing and harassment of marine mammals by motorboaters occurs in CINMS and can have significant impacts on the subjected animals (NRC 2003, Howorth 2004). Also, research elsewhere has shown that at high densities (i.e. groups of commercial and private whale watching boats following a group of whales), small vessel traffic noise can have significant impacts on groups of cetaceans, through the induction of hearing loss and the associated increased difficulties in foraging and intraspecies communication, and through the reduction of individual health associated with chronic stress (NRC 2003, Erbe 2002).

Acoustic emissions from oil production and acoustic thermometry are discussed; scientific and anecdotal evidence suggest that sound from these activities have little ecological impact within the Sanctuary at present compared with other noise sources.

In sum, science to date supports the conclusion that anthropogenic noise represents a potential threat of sufficient magnitude to Sanctuary resources to warrant precautionary management. While understanding of the biological and ecological importance of noise and sound remains incomplete, significant data exists to strongly implicate anthropogenic noise in major impacts to individuals and populations of cetaceans and fishes. Factors such as long-range transience, long life span, slow birth rate and size combine to make conclusive investigation of the short and long-term effects of human noise on great whale survival and reproduction extremely challenging at present, perhaps unfeasible. Because significant data and expert consensus support the conclusion that human noise has

significant impact on marine wildlife, specifically noise of a similar character to that presently emitted in and around the Sanctuary, waiting for such data to implement conservation-oriented management of harmful human noise may further imperil already endangered great whale species, as well as endanger other CINMS biological resources. The potential for environmental detriment to the Sanctuary from anthropogenic noise that is suggested by current scientific research outweighs the potential benefits from further inaction.

III. Recommendations

To acknowledge and address noise pollution in the Sanctuary, two sets of recommendations are proposed for adoption by the CINMS Sanctuary Advisory Council (SAC). The first set, "*Sources and Impacts*," outlines scientific research needed to assess Sanctuary impacts from noise and to inform decision making. It includes recommendations to: (1) Initiate Sanctuary-wide noise monitoring; (2) Study the hearing capabilities of Sanctuary wildlife; (3) Study anthropogenic noise impacts on Sanctuary ecology; and (4) Research indirect anthropogenic noise impacts to Sanctuary ecology.

The second set, "*Policy and Partnerships*," includes recommendations for generating momentum and leadership to address Sanctuary noise pollution through both collaboration and regulation. Specifically, recommendations include: (1) Establish a vessel traffic monitoring program to log and quantify ship traffic through the Sanctuary; (2) Develop inter-agency partnerships; (3) Engage the shipping industry in dialog and collaboration; (4) Research international policy and regulatory options; and (5) Create a role for the CINMS Advisory Council's Scientific Advisory Board to assist the CINMS in designing and implementing relevant research projects as well as in reviewing and responding to acoustic activities that may impact Sanctuary resources.

INTRODUCTION

Since the industrial revolution, the character and scale of human interaction with the ocean has changed dramatically. The emergence of mechanization facilitated a vast expansion in human oceanic activity, from the exploitation of marine resources to sea-borne transportation. The onset of steam, diesel and nuclear-powered engines also brought to bear an unprecedented ensonification (filling with sound) of the global oceanic environment, a phenomenon that has continued and expanded since industrialization as noise-producing human marine activity increases and spreads.

Many marine animal species, especially vertebrates such as fish and marine mammals, have evolved to rely heavily on hearing and sound production for an array of biologically critical behaviors, because of how efficiently acoustic energy moves through seawater (in contrast to light or scent). However, the variety of sound-based adaptations, such as echolocation, intra-species vocal communication, and acute hearing (used variously for navigation, detecting threats, and finding food or mates), all emerged in a pre-industrial acoustic environment much quieter than that of the heavily human-exploited oceans of today. Consequently, the significant increases in anthropogenic noise and the associated alteration of the marine acoustic environment may have biological implications on an array of levels, from the usefulness of an individual animal's hearing systems to the reproductive success of entire populations. Depending on the character of human noise pollution and the animals involved, known impacts from exposure have ranged from barely perceptible avoidance behavior, to severe physiological trauma and death.

Today, many human activities that purposefully or incidentally generate underwater noise are conducted throughout the world ocean, including: commercial and military shipping; use of active sonars for naval navigation, tactical and strategic operations; seismic surveying for fossil fuel prospecting and geologic research; operation and maintenance of oil drilling and production platforms; acoustic thermometry of oceans; marine aviation; marine construction including use of explosives, dredging and pile-driving; and commercial and private small vessel traffic for activities such as fishing, ferrying, whale watching, and recreational boating.

The extraordinarily productive and diverse ecology of the Channel Islands National Marine Sanctuary (CINMS, or the Sanctuary) today faces an extraordinary level of exposure to anthropogenic noise from many of these activities. With waters situated between two of the world's busiest ports, above active oil leases, and near major naval centers, CINMS sustains ongoing noise emissions from an array of human activities conducted within its boundaries related to these characteristics. What's more, the same ecological diversity and productivity of the Channel that provoked marine sanctuary designation will continue to attract noise-producing motorboat traffic for fishing, whale watching, and sight-seeing. Finally, certain scientific and military activities, and the passage of the largest tankers and cargo ships, produce extremely loud sound that can still

be detectable or influential to certain species within Sanctuary waters even if those activities occur tens or hundreds of kilometers away.

A complex mix of sound produced by human activities, in concert with sound from ongoing natural phenomena including weather, seismological dynamics, wave action and animal noises, comprise the general background din of any marine environment. However, based on measured sound emissions from large ships and the volume and consistency of freighter and tanker traffic traveling through and around the Sanctuary, large cargo vessel traffic represents the single greatest contributor—and thus the single greatest ongoing threat—to the CINMS acoustic environment. Military use of low- and mid-frequency active sonars, and commercial and scientific high-energy seismic surveying, while much more isolated and incidental in occurrence, also represent threats of negative impact to CINMS biodiversity based on the significant physical trauma, alteration of behavior, and even lethality to marine wildlife associated with these activities in other areas around the world. And, central to examination of anthropogenic noise pollution in the Sanctuary, economic and geopolitical trends strongly suggest global and local increases in shipping, and, longer-term, in seismic surveying and active sonar use as well.

Scientific research on marine bioacoustics and noise impacts on marine wildlife has accelerated and matured in the last ten years, since its (approximate) inception in the early 1970's. In the 1990's, proposals for activities such as shipshock trials by the US Navy, the ATOC project (Acoustic Thermometry of the Ocean Climate), and naval low-frequency active sonar decisively focused both public and scientific attention on the ecological impacts of anthropogenic noise, particularly on whales and dolphins. In 1995, William Richardson and colleagues published *Marine Mammals and Noise*, a text that continues to serve as the backbone of many marine bioacoustics and anthropogenic noise pollution investigations. Since then, scientists have expanded our understanding of cetacean and pinniped bioacoustics, as well as our understanding of fish biological and ecological use of sound, through field observations and laboratory experiments.

Unfortunately, due to both the relatively recent focusing of scientific investigation on marine bioacoustics, and the unique challenges associated with researching oceanic wildlife (particularly the large, endangered whale and dolphin species, which can be both highly elusive in the field, and for which laboratory-based research is prohibitively impractical due to their size), many important questions about how marine creatures use sound—and are impacted by noise—remain unanswered. For example, direct testing of hearing ability (to ascertain sensitivity and hearing range) has yet to be conducted for any baleen whale species, while little is known about how marine mammal acoustics depend on seasonal, diurnal, or geographical contexts beyond a few studied species. Despite the presence of much circumstantial evidence, little direct research has been done on the impact of elevated background noise (rather than isolated, impulsive sound) to various marine species. Significant discoveries in hearing and vocalizations in fish species (many of which aren't yet understood) have occurred just within the last few years, and reptile and invertebrate bioacoustics remain largely unexplored.

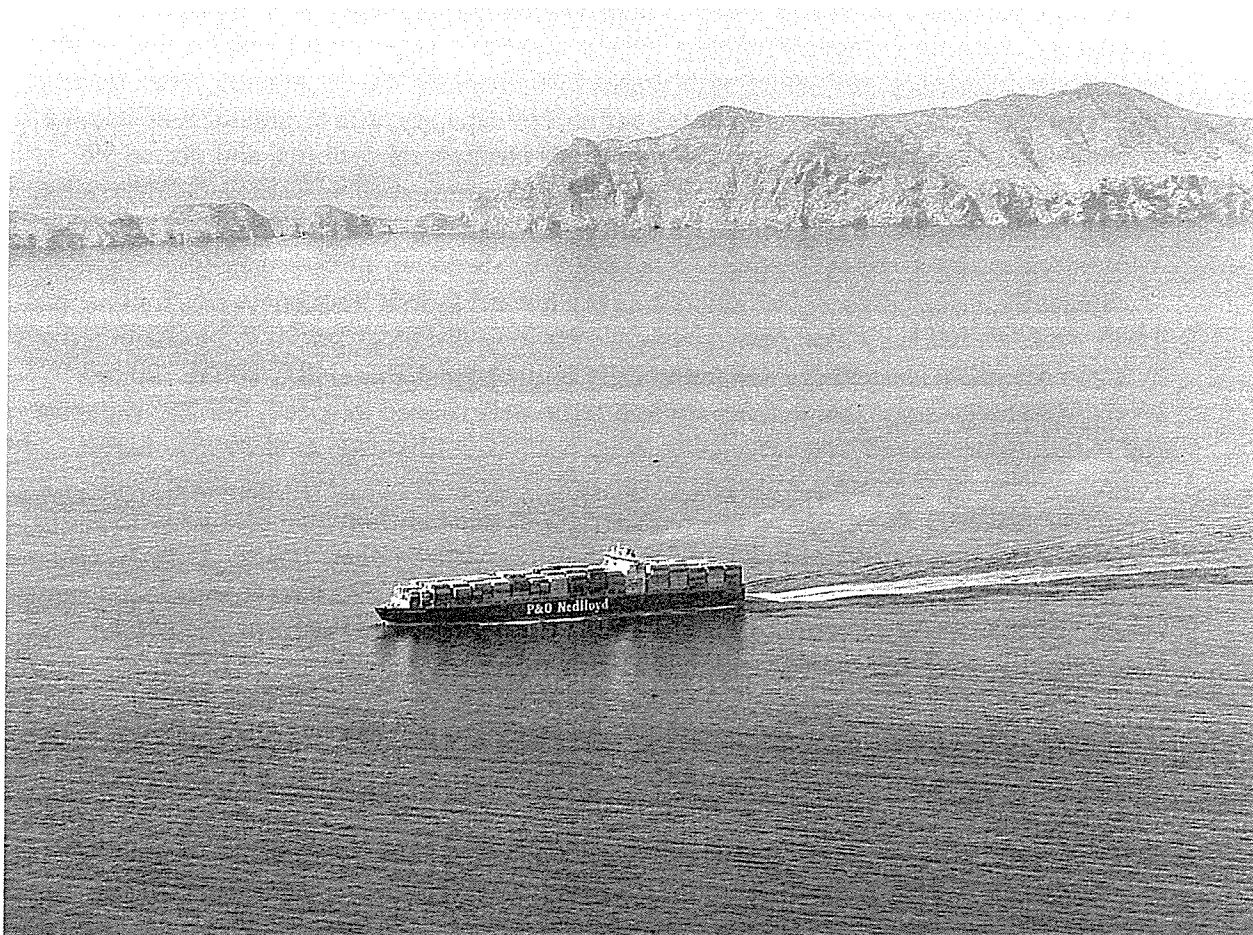
While current scientific understanding of the ecological impacts from anthropogenic noise remains incomplete, existing data on the impacts to marine mammals and fishes from human-generated sound demonstrates consequences ranging from negligible to traumatic to fatal for individuals of these biological communities. In fact, sufficient data exists to identify alteration of the underwater acoustic environment of the CINMS from anthropogenic noise as both a considerable and increasing threat to the Sanctuary's ecology. Of particular concern are the Sanctuary's rorqual whale species, already endangered from decades of commercial whaling, which may be especially sensitive to the types of noise pollution most prominent in CINMS.

This document reviews existing biological and bioacoustics research pertinent to the Sanctuary's acoustic environment and its sound-dependant marine species, and summarizes the noise-producing human activities in and around the Sanctuary that may be impacting them. Other human activities known to produce significant underwater noise but that don't appear to threaten CINMS resources at present, such as acoustic thermometry, will also be discussed. Taken collectively, existing data, anecdotes and bioacoustical/ecological expertise strongly indicate the need for prompt precautionary management of anthropogenic noise in CINMS, to countervail the dramatic—and increasing—alteration to the Sanctuary environment caused by human noise. The imperative to respond with precaution to anthropogenic noise in CINMS must be acted upon in concert with active, Sanctuary-specific research on the acoustics and acoustic ecology of its wildlife, toward the goal of management that balances conservation of the Sanctuary's special resources with the important economic activities of Southern California.

This document is organized by human activity. Sources of anthropogenic noise that impact or potentially threaten CINMS ecology are outlined and discussed in order of decreasing magnitude of threat, as assessed based on current research. Species and biological communities in the Sanctuary that are or may be impacted by each particular activity are detailed within each activity's section. Different anthropogenic noise sources may have the same or dramatically different known and potential impacts, based on differences in intensity, duration, character and proliferation of the causal human-generated activity, thus the necessity for a wide-ranging discussion. Beyond scientific review and discussion, the document will conclude with ideas for specific science and policy research with the potential to better inform and facilitate management of noise pollution in CINMS. A list of citations and an appendix appear at the end of the document, with background information on a few important acoustics concepts including measurement of sound intensity (including definition of the *decibel* and some basic physics of sound propagation), and the biological phenomenon of *masking*.

A final note: three documents, *Sounding the Depths* (NRDC 1999), *Oceans of Noise* (WDCS 2003), and *Ocean Noise and Marine Mammals* (NRC 2003) each attempt to provide summary coverage of underwater noise and marine wildlife. The latter two works provide up-to-date review and synthesis of research to date on marine bioacoustics

and anthropogenic noise, and were thus extensively relied upon for the present discussion. Similarly, *Marine Mammals and Noise* (Richardson et al. 1995) exhaustively gathers and organizes marine mammal bioacoustics science up to its date of publication, and is thus the core text for understanding many fundamentals of the field. These works are recommended for further information on anthropogenic noise and marine ecology.



A loaded southbound container ship passing by Anacapa Island (photograph courtesy of Channel Islands National Marine Sanctuary).

LARGE VESSEL TRAFFIC

Large vessel traffic is the principle source of noise in the World Ocean (NRC 2003, Croll et al. 2001), and in the Channel Islands National Marine Sanctuary (Pierson 2004, CINMS 2003(a)). This pre-eminence is due to a combination of factors, including the properties of sound emitted underwater by cargo vessels, the geographic location of the Sanctuary relative to major ports and shipping lanes, and the growth and increasing interconnection of the global economy and international trade.

Large cargo vessels, defined by Lloyd's Register as ships 100 gross tons (gt) or larger (Westwood et al. 2002), and loosely by Richardson et al. as ships approximately 85m or greater, individually produce significant sound emissions. Ship propulsion and electricity generation engines, engine gearing, compressors, bilge and ballast pumps, as well as hydrodynamic flow around the ship's hull and any hull protrusions all contribute to a large vessel's noise emissions (NRC 2003). All prop-driven vessels also generate noise through *cavitation*, a process in which the rotating propeller continuously creates bubbles in the water it passes through due to pressure gradients across the spinning propeller blades; the bubbles then immediately collapse under the ambient water pressure. Cavitation accounts for approximately 85% or more of a large vessel's noise, and tends to be lower in frequency and louder with vessel size (Ross 1976). In general, older vessels tend to produce significantly more noise per unit of capacity, due to greater inefficiency in design and poorer operating condition of older mechanical systems, and due to the increased cavitation of propellers with more imperfections such as imbalance, corrosion, damage and barnacles, which tend to accrue with vessel age (Richardson et al. 1995).

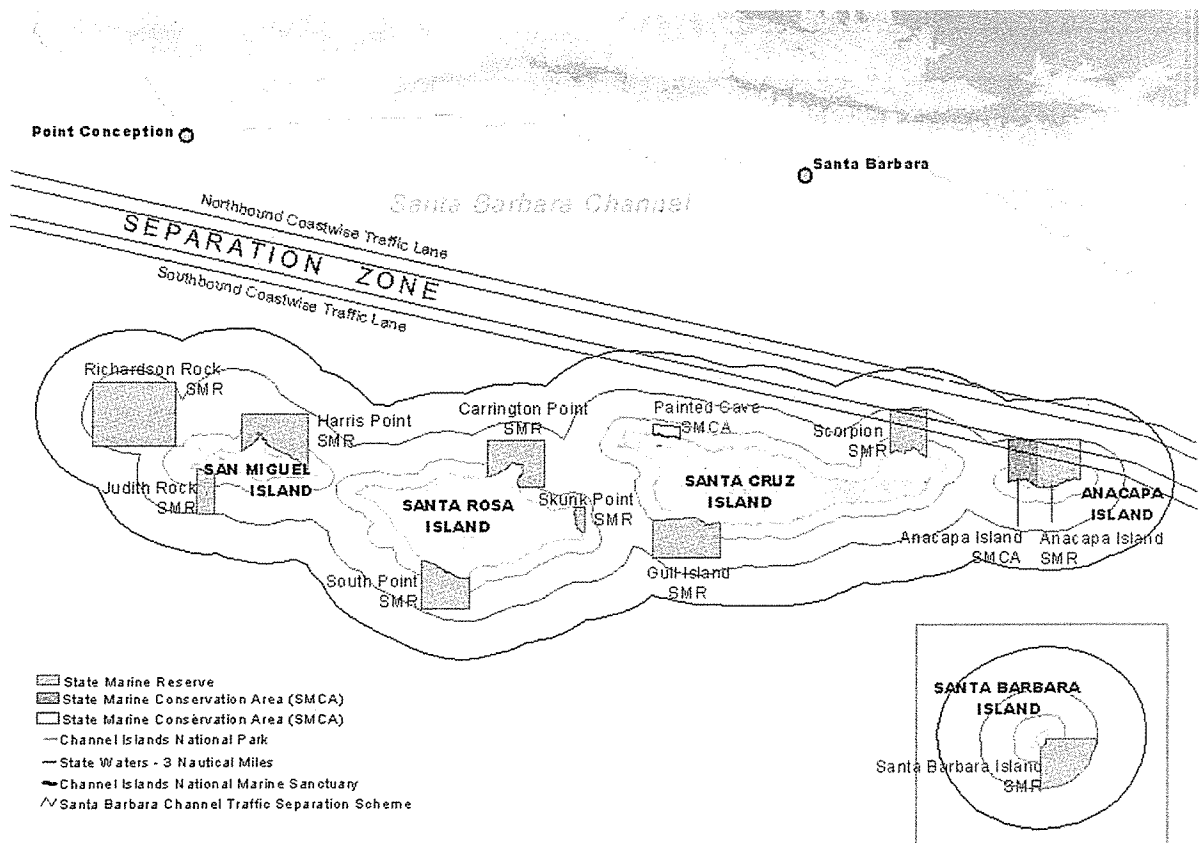
Sonically, large cargo vessel noise is characterized as low frequency, continuous, and tonal, while its intensity¹ and pervasiveness over long distances lead it to be characterized by some scientists as spatially and temporally indistinguishable (NRC 2003). Sound levels from cargo ships and tankers are approximately related to speed, burden, capacity and length (Gordon and Moscrop 1996, WDCS 2003, Richardson et al 1995). Large container vessels, freighters and tankers ranging from 135m to 337m generate peak source sound levels from 169 to approximately 200 decibels between 8Hz and 430Hz (WDCS 2003 summarizing an array of research, Richardson et al. 1995). Importantly, the physical properties of low-frequency sound and seawater combine to minimize sound absorption and facilitate sound propagation: sound energy travels approximately 4.5 times faster in seawater than in air, and while a high frequency sound of 100 kHz loses 36 dB in intensity per km, the intensity of a medium or low frequency sound (< 1 kHz) decreases no more than 0.04 dB per km (Richardson et al. 1995). As a result, low-frequency tones from a single large vessel are evident in sound readings 139-463 km away (Ross 1976), demonstrating the vast geographic area of ensonification from just a single large vessel. As NRC reports, the high sound levels of cargo vessel emissions make it so "very large geographic areas are affected," and even distant vessel traffic "contributes to the general acoustic environment" (2003).

Between 1985 and 1999, world sea-borne trade increased by 50 percent, to approximately 5 billion tons of cargo per year. During 1990-1998, annual growth in shipping-based trade averaged 3.2%; by 2002 more than 95% of world trade by tonnage was transported by large cargo vessels (Westwood et al. 2002). Because no transportation alternative exists to convey cargo at such scale, merchant vessel traffic will continue to increase in proportion to the growth of international trade and the global

1/ For definitions of important acoustic terminology and basic coverage of acoustics concepts such as *frequency*, *amplitude* and the decibel scale, see *Appendix A*.

economy (NRC 2003). While the number of vessels in the global merchant fleet is increasing, cargo vessels also continue to increase in size. Between 1982 and 2002, Lloyd's Register data show that the world's large vessel fleet grew from 73,832 to 88,168 ships (a trend that suggests a global fleet of more than 130,000 vessels (or similar shipping capacity) by 2026). Meanwhile, since 1970 the average vessel size has grown by 43% from 4,337gt to 6,201gt (Westwood et al. 2002).

Global shipping capacity is understood to be concentrated in the northern hemisphere, facilitating trade between the north's industrialized nations (WDCS 2003), and along defined routes and coastlines (NRC 2003), all characteristics of the Santa Barbara Channel area. More specifically, the global expansion of large commercial ship traffic pertains to CINMS because of the Sanctuary's location between the ports of San Francisco and Los Angeles/Long Beach, which, as the 18th and 10th busiest ports of call in the world respectively in 2000 (US DOT 2002) receive the bulk of Asian exports to the United States (Wignall and Womersley 2004). In fact, LA/LB and San Francisco are respectively the first and third busiest ports for container ship arrivals in the US, and projected to increase their containership arrivals by 5-10% per year over the next ten years (Wignall and Womersley 2004).



CINMS and the Santa Barbara Channel Vessel Traffic Separation Scheme (map courtesy of Channel Islands National Marine Sanctuary).

Large merchant vessels that arrive at or leave from these two ports bound for many other domestic and international ports travel the North- and Southbound Coastwise Traffic Lanes through the Santa Barbara Channel under the “Vessel Traffic Separation Scheme” (VTSS), which routes ships directly through the northeast end of the Sanctuary. Traffic enters and exits almost due east of Anacapa Island; northbound traffic exits the Sanctuary approximately 2 miles north of Scorpion State Marine Reserve on Santa Cruz Island, and southbound traffic enters the Sanctuary approximately six miles north of Painted Cave State Marine Conservation Area on the west end of Santa Cruz Island (NOAA/CINMS 2003). In 2002, approximately 6500 north and southbound cargo vessels traveled through the Channel and the Channel Islands National Marine Sanctuary, roughly 17 ships per day². Along with traffic between the various West Coast ports, container ship traffic traveling between LA/LB and Asian ports also passes through the Channel following navigation routes that trace a northerly arc across the Pacific.

As discussed, large vessels are *individually* very significant sources of underwater noise. However, because of the low attenuation rate of the characteristic low-frequency sound emission, and an average ship passage rate of about 84 minutes (yielding an estimated average vessel separation distance of 21 nautical miles), CINMS ecology faces essentially incessant, cumulative exposure to ubiquitous large vessel traffic noise. With about 120 ships transiting per week, any respites from large vessel noise are countervailed by concurrent passage of multiple ships. In addition, based on global trends, CINMS faces an increasing volume of vessel traffic, comprised of ships of increasing size (and, consequently, loudness) (Wignall and Womersley 2004).

In its preliminary draft Management Plan Update, CINMS identifies large vessel traffic as the “principle source of low-frequency noise” in the Sanctuary (CINMS 2003(a)). This conclusion is reinforced by the aforementioned data on the propagation and intensity characteristics of noise from ships (Richardson et al. 1995, Roussel 2002), by the proximity of the Sanctuary to the flow of commercial vessel traffic (the northern shores of all Channel Islands from Richardson Rock to Anacapa are less than 30km from the Southbound Coastwise Traffic Lane, and no more than 2km from the shores of Anacapa Island (NOAA/CINMS 2003)), the current and projected quantity of traffic in Southern California (Wignall and Womersley 2004) and thus low-frequency sound production, and the stated opinions of several experts (Pierson 2004, Clark 2004, Croll et al. 2001).

2/ Unfortunately, no systematic monitoring of large vessel traffic passing through the Santa Barbara Channel is known to exist. The Southern California Marine Exchange (a San Pedro-based non-profit non-governmental organization) maintains a database of all vessels entering and leaving LA/Long Beach, including each ship’s previous port of call and destination port. By counting ships arriving in LA/LB from a northern origin, or departing for a northern port, an estimate of passage rates through the Santa Barbara Channel can be achieved. However, this lack of direct traffic monitoring through the Sanctuary should be considered a significant gap in the needed management and understanding of noise and any other impacts large vessel traffic may have on the Sanctuary.

This assessment is also buttressed by anecdotes and marine acoustics research conducted in Central and South Coast offshore areas specifically. Ross (1976), using a Navy hydrophone array, documented a 15dB increase in 5-100Hz noise off Point Sur between 1950 and 1975 which he attributes solely to increased ship traffic (and noted that 6.8 Hz noise from a supertanker could be detected 139-463 km away). Andrew, et al. (2002), building from Ross's data through observations with the same Point Sur hydrophone array, document a 10 dB increase in ambient oceanic noise at 20-80Hz between the early 1960s and the late 1990s, representing more than another full order of magnitude of increase. They also attribute the increase to greater vessel traffic³. In 1998, MIT researchers attempted an acoustics experiment in which seafloor hydrophones in the Santa Barbara Channel were employed to ascertain the location of a moving, ship-towed sound source emitting up to 170dB between 0 and 500 Hz. The experiment essentially failed due to unpredicted and overwhelming masking of the towed sound source across its spectrum by cargo vessel traffic noise from the north and southbound lanes of the Vessel Traffic Separation Scheme (VTSS) just northeast of Anacapa. At over 11km from the passing ships, the hydrophones received vessel traffic noise of over 125 dB, approximately 300 times greater than the received intensity of the researchers' towed 170 dB sound source (MIT 2000).

These reports begin to illuminate both the power and the wide-reaching effect of large vessel traffic in the Central and South Coast regions: not only is large vessel traffic noise the primary anthropogenic contribution to the CINMS acoustic environment, but in absolute terms establishes CINMS as an exceptionally ensonified (i.e. noisy) marine environment within the world ocean. Compared with its pre-industrial ambience, and the acoustic environment of remote, rarely traveled locations (see, for example, Cato 1976 for measurements of ambient acoustics off Western Australia), the acoustic environment of the Southern California Bight could be considered "urbanized" (Clark 2004).

From this basic understanding of the physical magnitude of large cargo vessel traffic and the sound it produces, discussion of the extensive known and potential ecological significance can begin. In sum, research to date on the impact of low-frequency noise upon various marine species raises the possibility of several negative outcomes for CINMS biodiversity resulting from the intense and pervasive sound of large vessel traffic. These include persistent masking of ecologically vital sound for marine mammals and fishes, temporary and permanent threshold shift in marine mammals and fishes, avoidance of important and historical habitat and the manifold secondary ecological consequences of these impacts. Each will be discussed in turn below⁴.

3/ Perhaps more precisely, the increase is due to a combination of increase in total vessel numbers as well as average vessel tonnage.

4/ Marine bioacoustics research has to date largely focused on cetaceans (Popper 2003, NRC 2003). To a lesser extent, pinnipeds, fishes, sea turtles, and some cephalopods and crustaceans have also been studied or have had behavioral responses documented (NRC 2003, WDCS 2003). This discussion focuses on the biological communities for which meaningful acoustics research has been conducted and published, namely whales and fishes. Hopefully future bioacoustics research will broaden as well as

Several species of baleen whales (members of suborder Mysticeti) inhabit the Sanctuary area, including gray whales (*Eschrichtius robustus*), and at least four members of Family *Balaenopteridae*, including blue whales (*Balaenoptera musculus*), fin whales (*B. physalus*), sei whales (*B. borealis*), and humpback whales (*Megaptera novaeangliae*) (CINMS 2003(b)). Among the balaenopterids, recordings of vocalizations and documentation of conspecifics' reactions to those vocalizations imply significant reliance on sonic communication in the low frequency range, 5-500Hz (Croll et al. 2002, WDSCS 2003, Roussel 2002), the same range in which large vessel traffic emits its most intense output (NRDC 1999, NRC 2003, Richardson et al. 1995). This overlap of the acoustic characteristics of anthropogenic sound and balaenopterid communication, i.e. masking⁵, has direct implications for CINMS blue and fin whale ecology and perhaps survival. These implications are just beginning to be elucidated.

Croll et al. (2002), through locating and sexing (via biopsy and DNA analysis) vocalizing fin whales in the Gulf of California, ascertained that all vocalizing animals were male. The researchers conclude that the patterned, 15-30Hz scooping calls characteristic of fin and blue whales are mating displays used by males to attract mates from long distances (to the order of hundreds of kilometers) to feeding and breeding areas, and they support this proposal with some key observations. First, "fin and blue whales do not aggregate in specific areas for breeding," unlike the related humpback whales, which gather in tropical waters during a definite breeding season. Second fin whales "use the Loreto (Baja California) study area to forage on dense aggregations of krill;" and finally, the "low-frequency vocalizations of [genus] *Balaenoptera* are optimal for long-distance communication in deep water" (Croll et al. 2002).

These findings illuminate the significance of the acoustic environment to balaenopterid reproduction, foraging and thus general survival; extremely pertinent to our discussion of CINMS acoustics, the researchers also address the interaction of anthropogenic noise and fin- and blue whale vocalizations:

Our results help to focus growing concern over the effects of human-produced sound on Balaenoptera species. Sound levels from commercial ships, military sonar, seismic surveys and ocean acoustic research are extremely high (190–250 dB) and, at least since the early 1960s, the amount of human produced sound in the frequency range used by large whales has increased (Andrew et al. 2002). A sound is detectable if its received level exceeds that of background noise by enough to be detected by the animal. An increase in ambient noise could thus reduce the distance over which receptive females might hear the vocalizations of males. To the extent that growth of Balaenoptera populations is limited by the

deepen current understanding, so that discussions such as this can include a more complete cross section of a region's ecology.

5/ NRC (2003) defines masking as "a reduction in an animal's ability to detect relevant sounds in the presence of other sounds."

encounter rate of receptive females with singing males, the recovery of fin- and blue whale populations from past exploitation could be impeded by low-frequency sounds generated by human activity. [Croll et al. 2002]

Fin and blue whales regularly inhabit CINMS and the greater Southern California Bight area, exploiting the productivity of waters in and around the Sanctuary to forage (CINMS 2003 (b)). Dr. Christopher Clark, a coauthor of Croll et al. (2001), Croll et al. (2002), and other cetacean bioacoustics studies, describes the Channel Islands area as rich with evidence of balaenopterid-whale breeding and feeding activity, including plumes of feces and vocalization noises (Clark 2004). Management of CINMS and its cetacean populations should thus be conducted with these conclusions, including orca whale sensitivity to low-frequency noise, in mind.

For all cetaceans, aforementioned mysticetes as well as the toothed whales (odontocetes), large vessel traffic noise may be associated with higher energy-costs involved in the modification of vocal echolocation and communication in noisy environments. Both baleen and toothed whales have been documented modifying vocalization to counteract masking from anthropogenic noise⁶, through increases in amplitude and frequency of vocalizations (NRC 2003). These modifications may also increase difficulty in foraging, navigation, and intra- and interspecies communication due to use of sub-optimal frequencies for these activities (NRC 2003).

In all known vertebrates, exposure to noise of sufficient intensity can result in temporary or permanent loss of sensitivity to sound at a given frequency range: threshold shift, as it is known, can occur instantaneously if the received sound levels are high enough, or can occur over time at lower intensities through continuous or cumulative exposure (Richardson et al. 1995). Temporary or permanent threshold shifting may occur in cetaceans, pinnipeds and fishes in the Sanctuary as a result of exposure to large vessel traffic noise because of its intensity, broad geographical effectiveness, and constancy, which collectively imply significant cumulative exposure to any individuals or populations exhibiting site fidelity. As discussed in the context of masking, impairment in sound sensing can significantly impinge on the survival of many marine species; published research on threshold shifting in marine wildlife, summarized below, suggests that harmful and fatal changes in normal behavior can result from hearing loss due to excessive exposure to underwater anthropogenic noise.

6/ NRC summarizes the key literature on masking and marine mammals: *Beluga whales increased call repetition and shifted to higher peak frequencies in response to boat traffic (Lesage et al. 1999). Gray whales increased the amplitude of their vocalizations, changed the timing of vocalizations, and used more frequency-modulated signals in noisy environments (Dahlheim 1987). The physiological costs of ameliorating masking effects have not been reported. Although these examples all appear to show animals adapting their vocal behavior to reduce the impact of masking, this does not imply that there were no costs resulting from increased levels of noise. Masking may have been reduced but not eliminated. [NRC 2003].*

André et al. (1997) studied the impacts of high-speed ferry traffic on sperm whales (*Physeter macrocephalus*) in the Canary Islands, including the application of low-frequency noise emitters from the ferries to deter sperm whales and reduce shipstrike. Sadly, attempts at acoustic deterrence with a variety of different sounds failed to significantly increase vessel avoidance, which the researchers suggest stemmed from sperm whale habituation to large vessels, or to threshold shift. Citing subsequent research by André et al. (1998), NRDC (1999) reports that two sperm whales in the Canary Islands were struck and killed by a cargo ship without any apparent attempt at avoidance. André et al. conducted necropsy on the whales, revealing discernable cell damage in the inner ears of both individuals. The researchers suggested that heavy vessel traffic was causing the discovered permanent threshold shift in the resident sperm whales, thus reducing or eliminating their awareness of approaching ships (1998).

Similar to the sperm whale research, Todd et al. (1996) reported on humpback whales in Newfoundland that were subject to potentially damaging levels of sound from underwater explosions (from marine construction) over the course of a season in historic and productive humpback feeding grounds. Explosions emitted maximum levels of sub-1000Hz sound estimated at 209 dB at the source, and measured at 153 dB approximately 1.8 km away. Humpback individuals were subject to the sound at a range of distances from the sound source, yet showed no significant change in behavior despite some extremely high, acute received sound levels. Over the subsequent two years, however, humpback entanglements in gill nets with sonic deterrence devices in the region dramatically spiked, from an average of 2.5/year from 1979 to 1990, to 19 and 14 recorded entanglements in 1991 and 1992 respectively.

The researchers suggest that the explosions resulted in threshold shifting sufficient to significantly impinge on the whales' ability to acoustically detect gill nets. While underwater explosions are dramatically different in acoustic character compared to large vessel traffic, the research of Todd et al. reveal that cetaceans, or at least humpbacks, may not flee from biologically important habitat despite physiologically traumatic sound levels.

All great whales known to inhabit CINMS (baleen and sperm whales) are understood to be transient (temporary or migratory inhabitants) (CINMS 2003(b), Calambokidis et al. 1998), which, in light of the aforementioned research, raises some troubling possibilities worth considering in the context of large vessel traffic and CINMS wildlife management.

First, balaenopterids that reside for any duration in the Sanctuary area are subjected to high ambient noise levels shown to both mask vital intraspecies communications for foraging and reproduction, and also cause either imperiling habituation to vessel traffic noise⁷ (and the ships themselves), or some degree of auditory threshold shift with the

7/ Bioacoustics researcher E. Gerstein points out the biological usefulness of habituation (in the context of Atlantic right whales): if whales in areas of heavy vessel traffic stopped feeding and fled at

same behavioral outcome of reduced avoidance. An increase in whale shipstrike over time could be the first telling result (analogous to that observed by André et al. (1997) in the Canary Islands), as sensitivity to aural cues and avoidance response diminishes. Such a hypothetical increase could be attributed simply to the ongoing increase in vessel traffic alone; nonetheless, an active and continuous monitoring program for shipstrike⁸ vis-à-vis vessel traffic volumes and whale distribution patterns would produce data valuable for understanding large vessel impacts on whale population dynamics. Furthermore, some form of active monitoring could provide opportunities to investigate the possibility of discernible damage to cetacean aural physiology through immediate necropsy of any ship-killed individuals.

Over a much longer period of time, a reduction in birth rate for balaenopterid whales inhabiting CINMS may also occur and be used as an indicator that the effective distance of male calls summoning females to krill plumes and sex in the Channel area is reduced due to masking from shipping noise (Clark 2004). Unfortunately, the long life spans and naturally slow reproduction rates of fin and blue whales make measurements in birth rate change a prohibitively long and slow process (such an endeavor would span human lifetimes), and passive observation of human-caused decline in these already endangered populations would be unacceptable.

Published reports on marine mammal avoidance and long term abandonment of historical habitat due to anthropogenic noise raise this scenario as a future possibility for CINMS and its surrounding waters, and should also be considered in light of increasing large vessel traffic. Bryant et al. (1984), studying gray whales (*E. robustus*) recorded abandonment of a calving lagoon in Baja California after initiation of dredging and an increase in small vessel traffic. Years later, cow-calf pairs were again seen in the lagoon after cessation of the noise-producing mechanical operations in the Lagoon. Similarly, Northwestern Pacific gray whales were documented abandoning historical feeding grounds near Sakhalin Island to avoid commercial seismic surveying noise (IWC 2004(a)) [this report is also discussed in the seismic surveying section]. Morton and Symonds (2002) report that in *orca* of the Pacific Northwest, transient and resident subpopulations were equally affected by the acoustic harassment devices (AHDs) deployed by the fish farms to deter predation from salmon pens in their study area. Both sub-populations completely abandoned their historical habitat within the study area until the AHD's were removed. While these subpopulations of *orca* are a unique feature of this species, the researchers' observation may be pertinent to our discussion in that two groups with distinct habitation and migration patterns both significantly altered their behavior due to introduction of anthropogenic noise.

every sign of an oncoming ship, they would never get to eat (informal comment at bioacoustics conference).

8/ NOAA Fisheries data report ten ship collisions with whales in the Santa Barbara Channel between January of 1983 and June of 1998 (NOAA Fisheries, California Marine Mammal Stranding Network Database 2004). However it is likely that not all strikes are observed or reported.